SUSY Reconstruction with Athena in DC1

Frank E. Paige, Brookhaven National Laboratory

For first SUSY full simulation chose mSUGRA point similar to Point 5 but consistent with current bounds ($M_h = 114.8\,\mathrm{GeV}$):

$$m_0 = 100\,\mathrm{GeV},\ m_{1/2} = 300\,\mathrm{GeV},\ A_0 = -300\,\mathrm{GeV},\ \tan\beta = 6,\ \mathrm{sgn}\,\mu = +$$

Has similar $\tilde\chi_2^0 \to \tilde\ell_R^\pm \ell^\mp$ (8.8%) signature. Also gives $\tilde\chi_2^0 \to \tilde\tau_1^\pm \tau^\mp$ (75%) and $\tilde\chi_1^\pm \to \tilde\tau_1^\pm \nu_\tau$ (68%) $\Rightarrow$ many τ's. Analysis chain [Athens, Note]:

- Generate 100k events with Herwig, using Isajet for SUSY input.
- Simulate ATLAS response with Atlsim (Fortran, GEANT 3.21), tracking each particle through detectors. About 15m/event.
- Reconstruct simulated data with Athena 6.0.3 (C++) to make Ntuple with physics quantities. About 1m/event (done many times).
- Analyse Combined Ntuple with Fortran code linked to Paw.

SUSY provides good test of reconstruction: complex events, many different signatures.

Have studied efficiency, purity, and resolution for jets, electrons, muons, taus, and $\not{E}_T$ with Athena 6.03/7.02.

No pileup has been included. Electronic noise turned off except as noted; significant effect for liquid argon calorimeters.

No Standard Model background. For physics plots, make same cuts as before $\Rightarrow$ expect $S/B \gg 1$.

Have learned a lot about real reconstruction of SUSY events over last year. Much more to do, but Athena reconstruction is already usable.

Have even managed to produce some new physics results.

Jet Reconstruction and Calibration

Have used two Athena jet algorithms for SUSY studies:

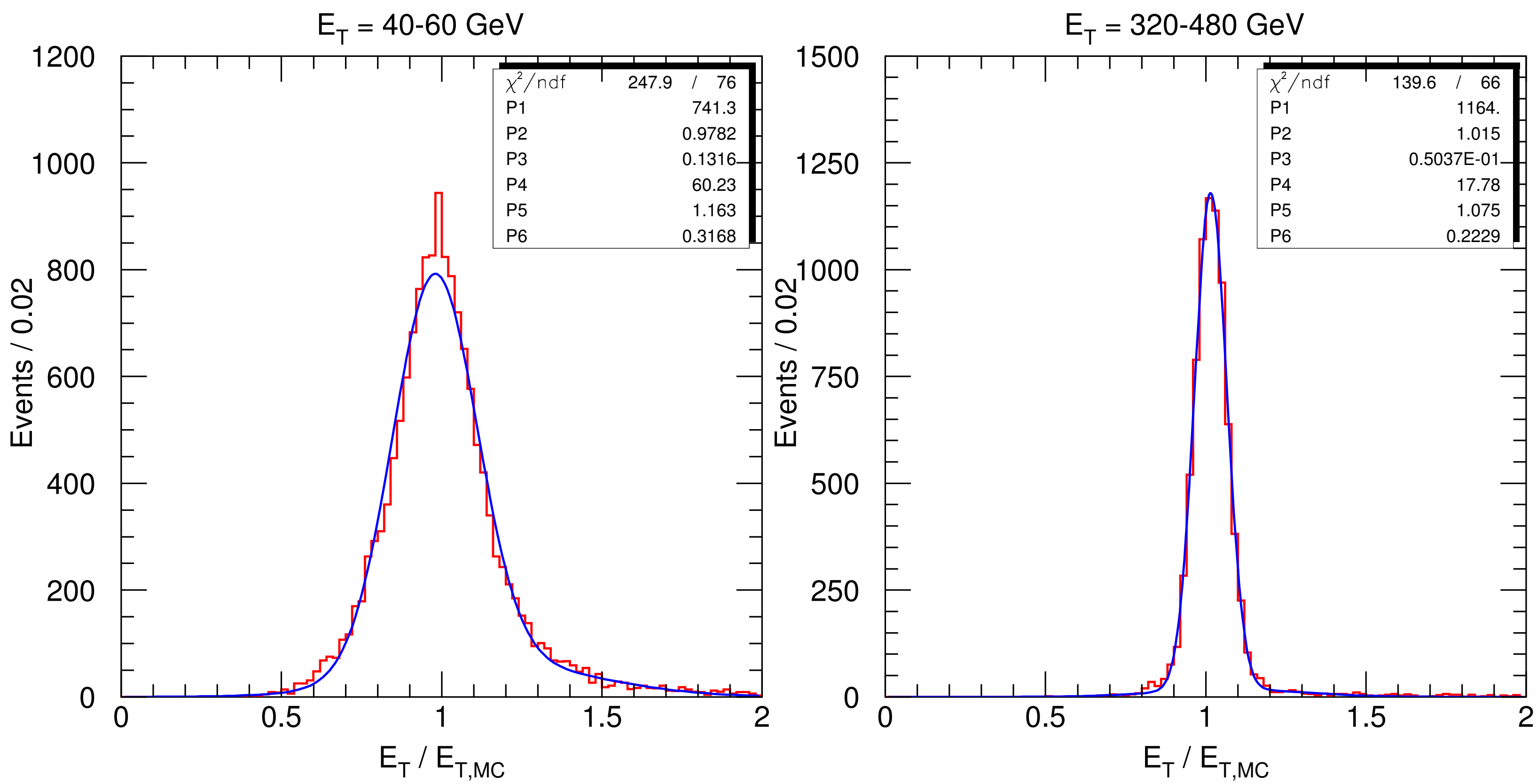
- (Seeded) Cone: Iterate cone with fixed R. Not infrared safe, but works OK in practice.
- K_T: Well optimized Cambridge code, but still $T \propto N^3$.

Calorimeter in Athena is calibrated at EM scale, so $\sim 15\%$ low for jets. *TDR* corrected for this using sampling weights.

H1 algorithm: EM showers are denser than hadronic ones, so use unit weight for high E_T-cells, larger weight for low-E_T ones.

To determine weights, sum cells in E_T bins for each jet and calorimeter section. Fit weights by comparing calorimeter jet with nearest jet made from MC particles using same jet algorithm.

Resulting resolution for 2 DC1 QCD jet samples:



Mean response is about correct and Resolution also somewhat better.

Same H1-style weights also improve $\not{E}_T$ resolution.

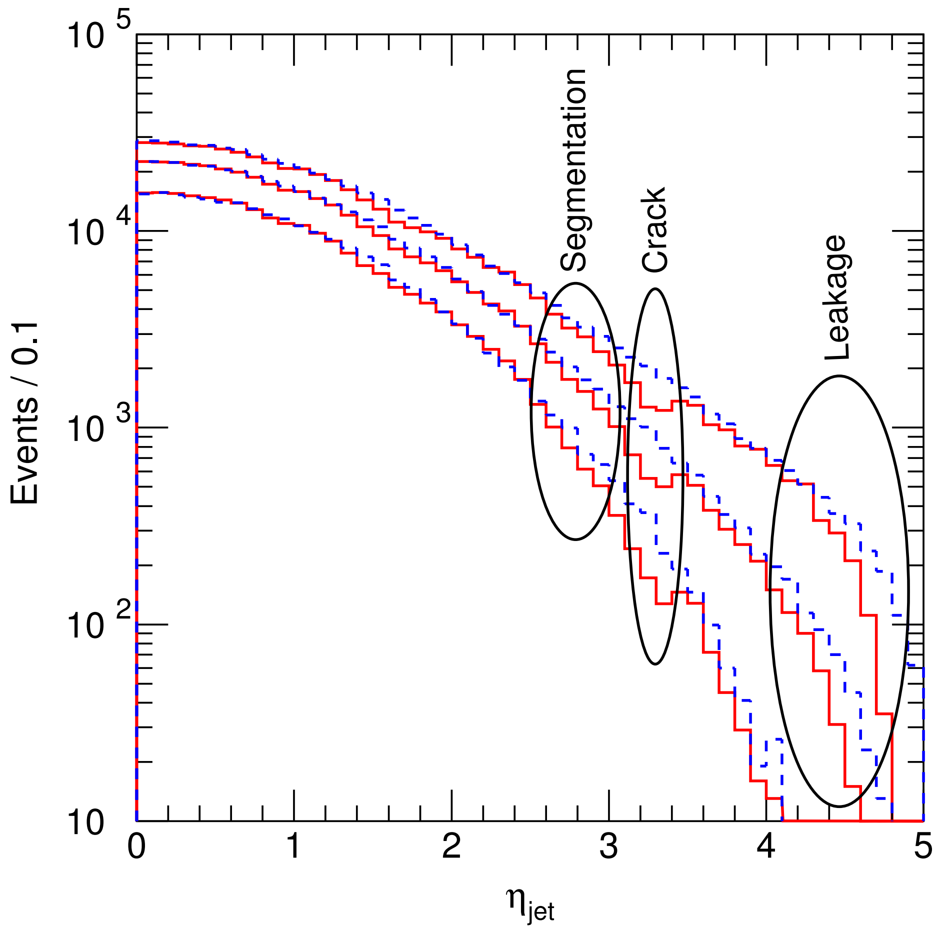
Reconstruct jets in SUSY using same weights, and again compare with closest MC jet. Compare reconstructed (solid) and Monte Carlo (dash) jets for $E_T > 25, 50, 100\,\mathrm{GeV}$:

H1 calibration also works for SUSY sample dominated by quark jets, but observe some problems:

Calorimeter segmentation changes at $\eta = 2.5$.

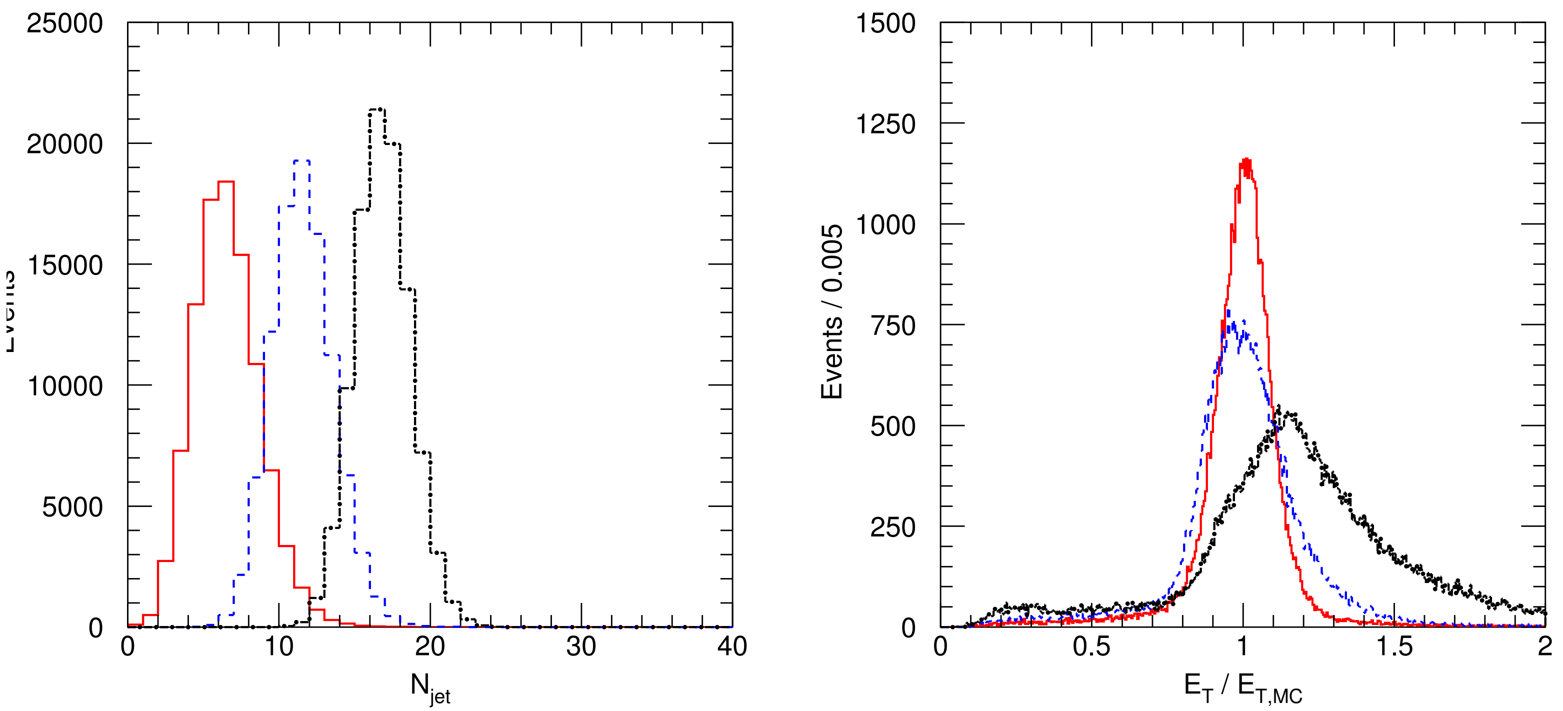
Crack between endcap and forward calorimeters at $\eta = 3.2$.

Shower leakage at large η.



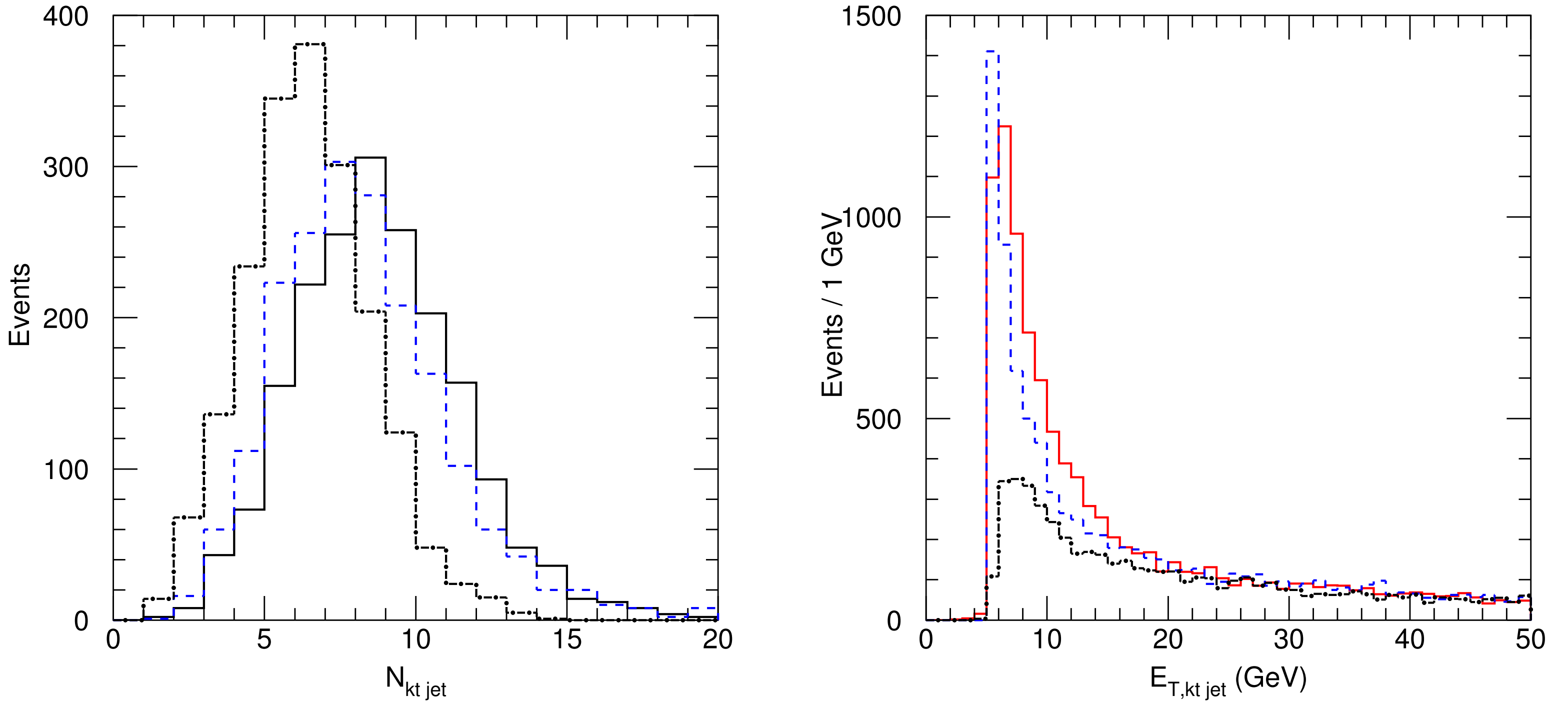
ATLAS

Just before Athens, included electronic noise but not pileup. KT algoritm requires $E > 0$. Huge effect with $E = 0$ cut (dash-dot), still large with $E = 2\sigma_E$ cut (dash) on multiplicity and resolution for $E_T = 80$–$120\,\mathrm{GeV}$:



Smaller effect for cone algorithm with $R = 0.4$, so many fewer towers.

Since Athens, have implemented cancellation of $E < 0$ `CaloTower`'s with nearby $E > 0$ ones and applied H1 weights before clustering. Much better agreement between Monte Carlo (dash) jets and reconstructed ones with (solid) than without (dashdot) preweighting:



Still not perfect; need a lot of work to achieve 1% hadronic energy scale and best possible jet energy resolution.

Electron Reconstruction

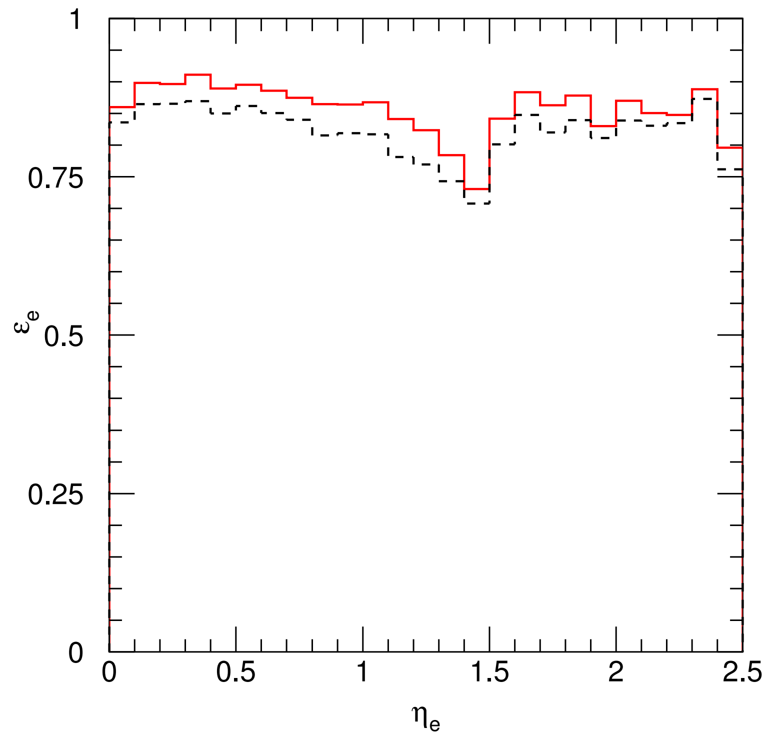
Electrons identified by shower shape (require `eg_IsEM` $= 0$) and matching track with $E/p \approx 1$.

Must make loose cut in endcap to get adequate efficiency:

$$0.8 < \frac{E}{p} < 1.3, \ |\eta| < 1.37$$

$$0.7 < \frac{E}{p} < 2.5, \ |\eta| > 1.37$$

Then efficiency for isolated MC electrons is $\gtrsim 85\%$.

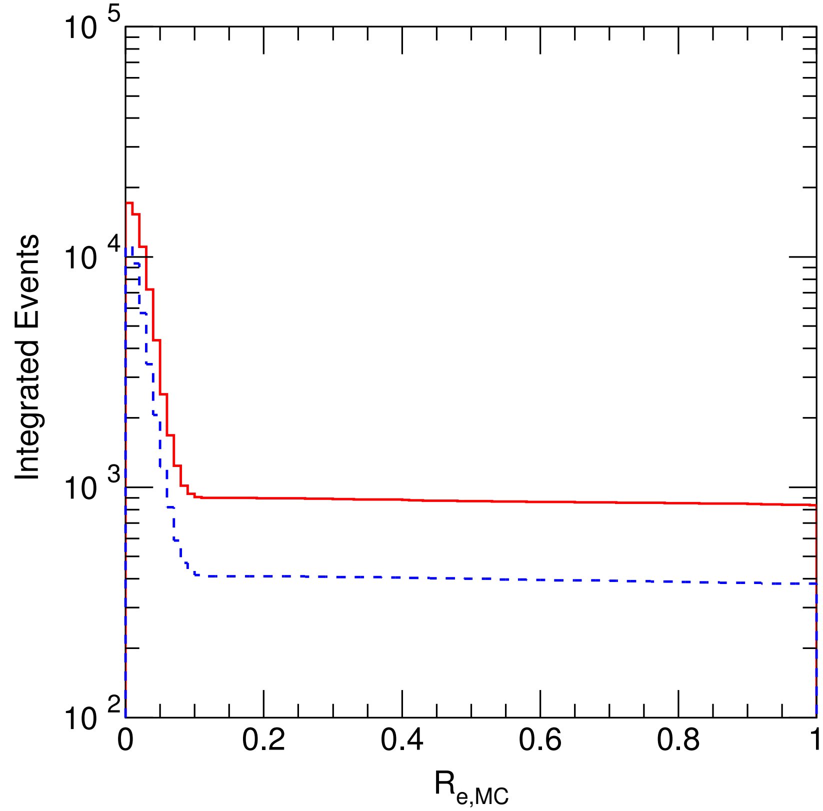


Efficiency depends weakly on E_T for $E_T > 10\,\mathrm{GeV}$.

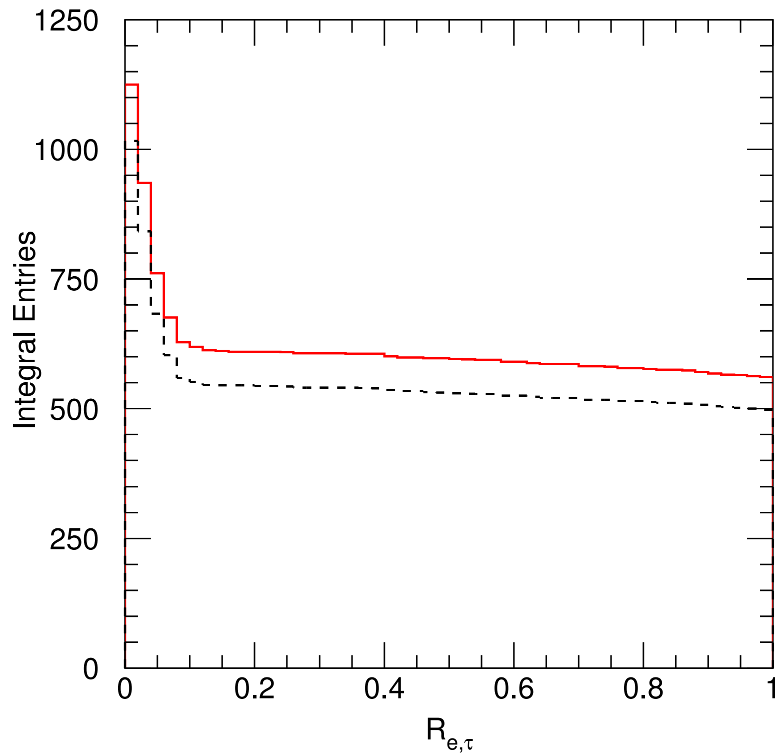
Plot integral distribution for $E_T > 10, 25\,\mathrm{GeV}$ of distance R between reconstructed e and closest MC one.

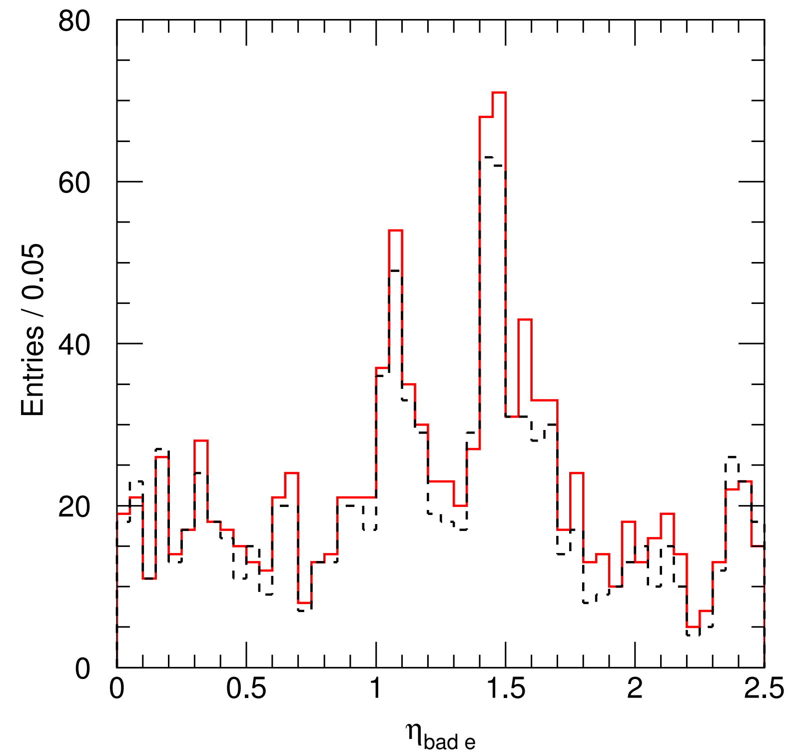
Mostly $R < 0.1$, but see $\sim 4\%$ fakes for $E_T > 25\,\mathrm{GeV}$.

If fakes are from jets, 6.3 jets and 0.16 electrons per event imply fake e/j rate is $\sim 10^{-3}$, worse than expected.



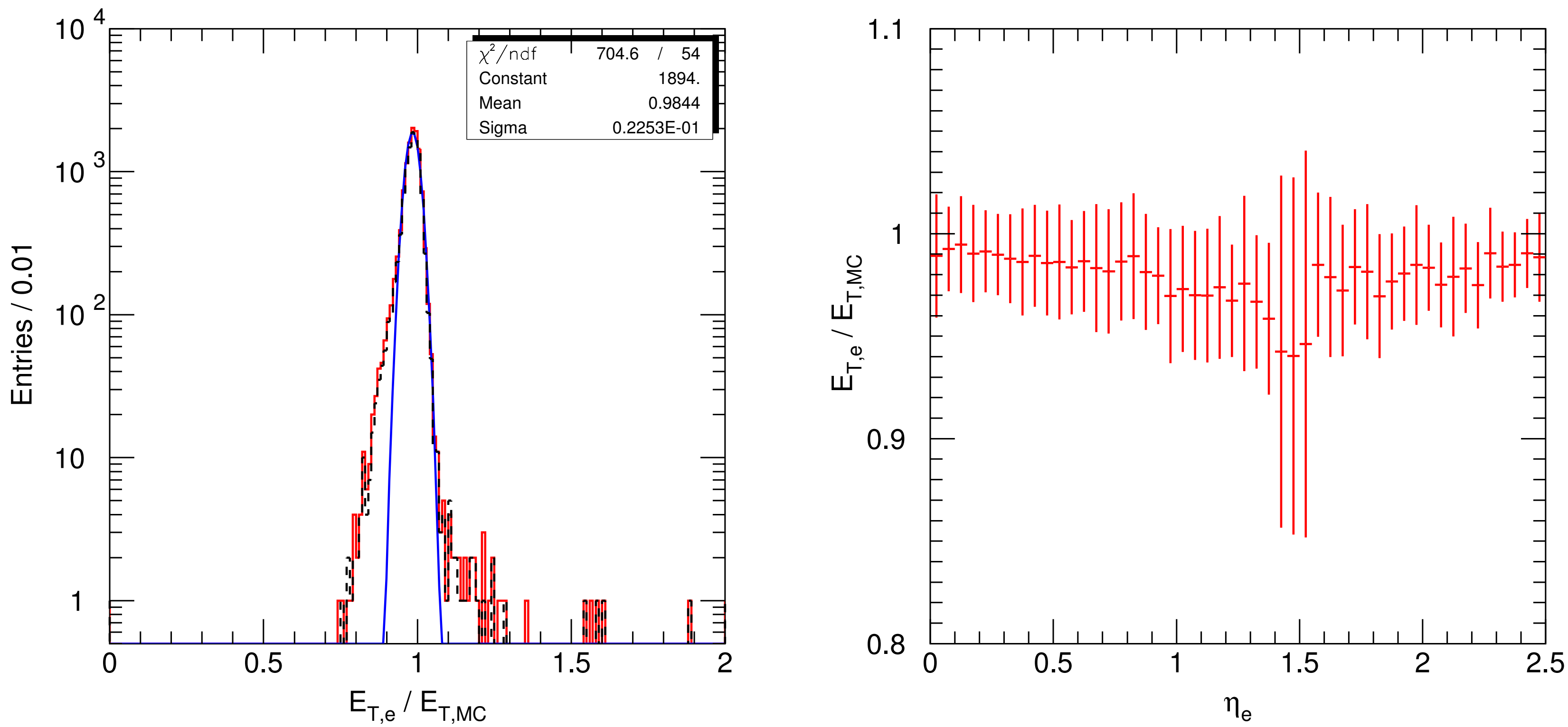
But half of fake e's are close to τ's, more like e's than jets. Fake e's peak at $\eta = 1.1$ near gap in HCAL:





Obviously need more work on *e* identification in complex events, e.g., with large τ background.

Resolution (compared to nearest MC e) for $E_T > 25\,\mathrm{GeV}$:

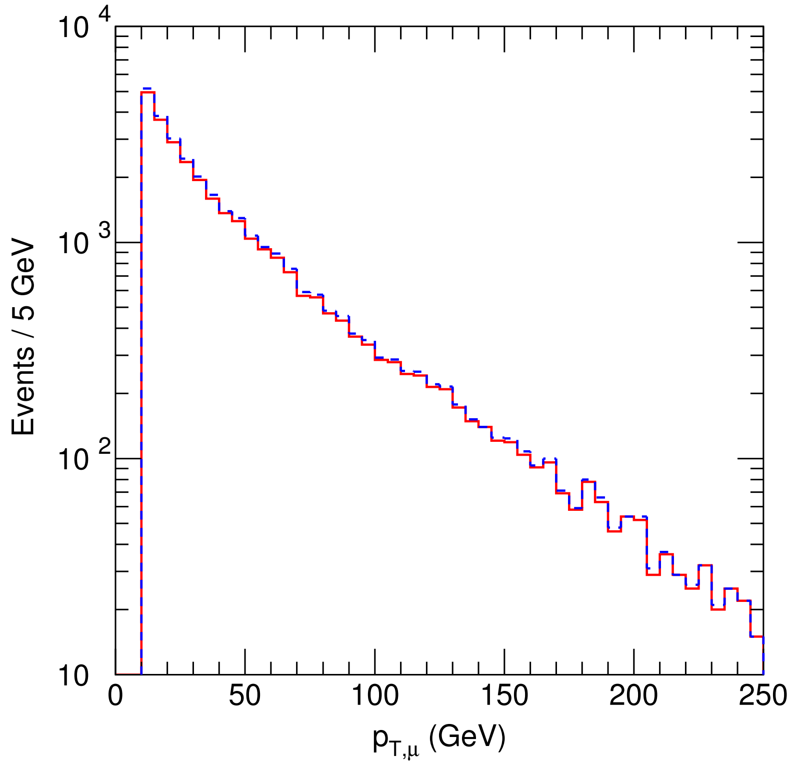


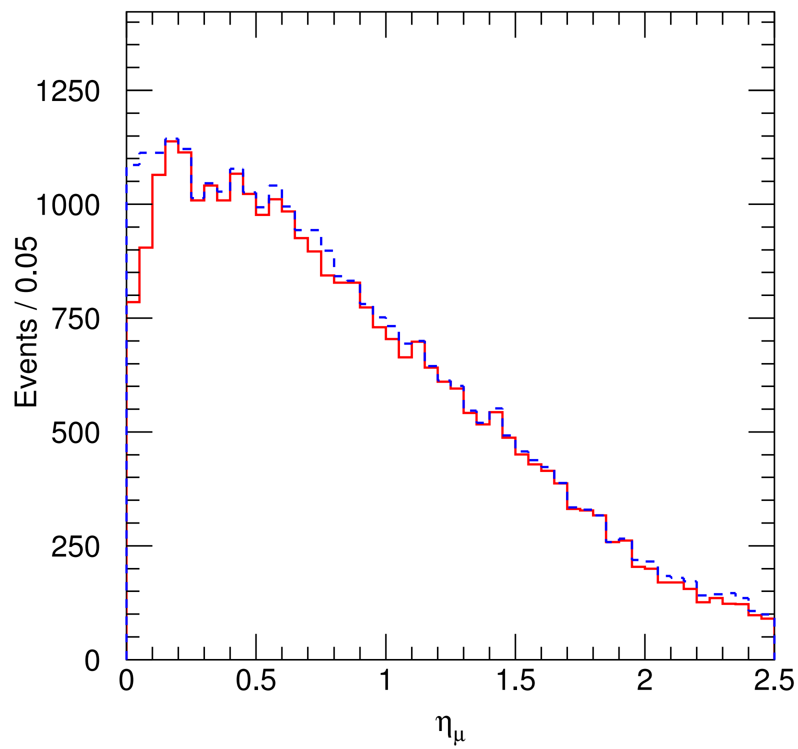
Gaussian fit gives 0.9844 ± 0.02253. Need brem recovery for radiative tail. Need work on e energy scale.

Muons

MuonBox gives excellent results – better than 90% overall acceptance.

Dip in acceptance at $\eta = 0$ due to holes for services:

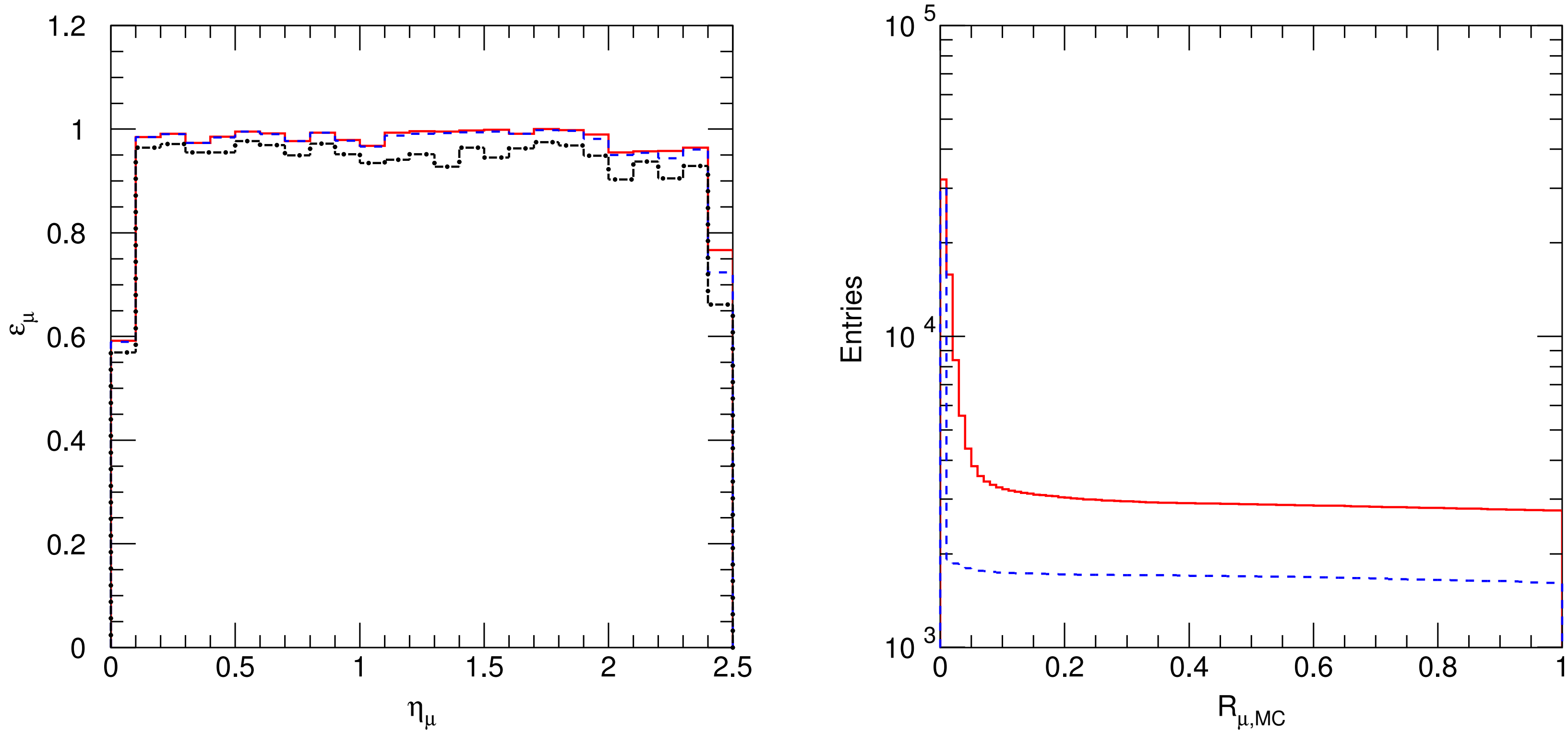




Matching of MuonBox with inner detector not yet in Athena.

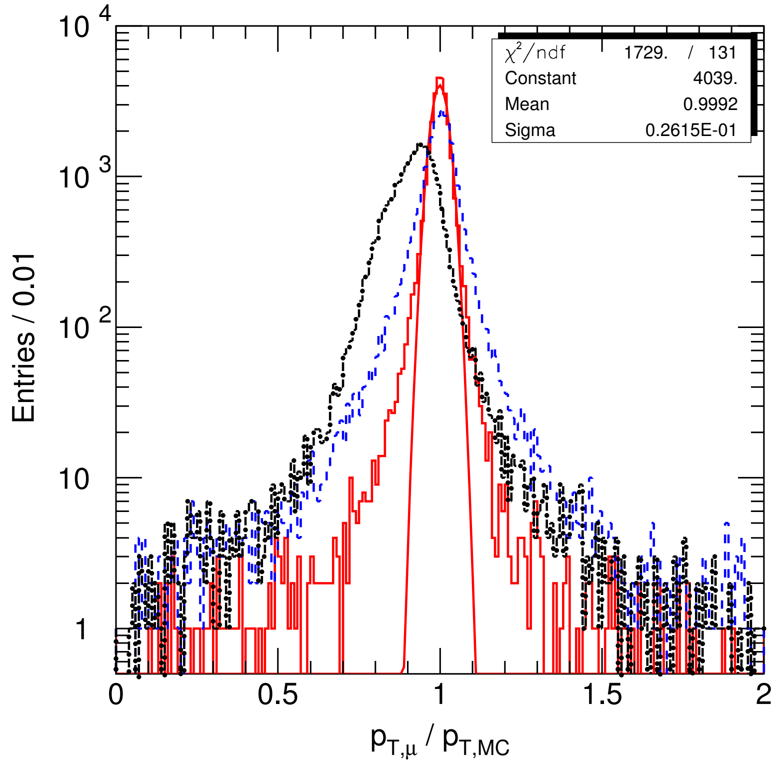
ATLAS

Moore/MuID available in 7.0.2. Matching to inner detector improves purity with small loss of accecptance:



Some background is from π, K decays.

Significant improvement in resolution for low-p_T muons. Resolutions for $p_T > 10\,\mathrm{GeV}$ with external, stand alone, and combined:

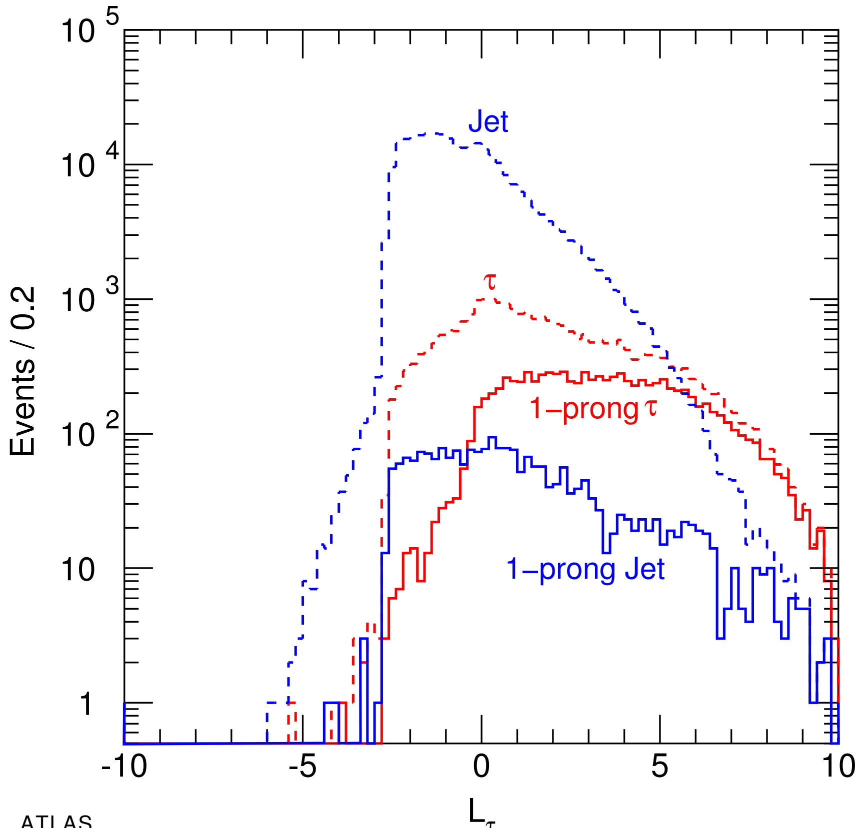


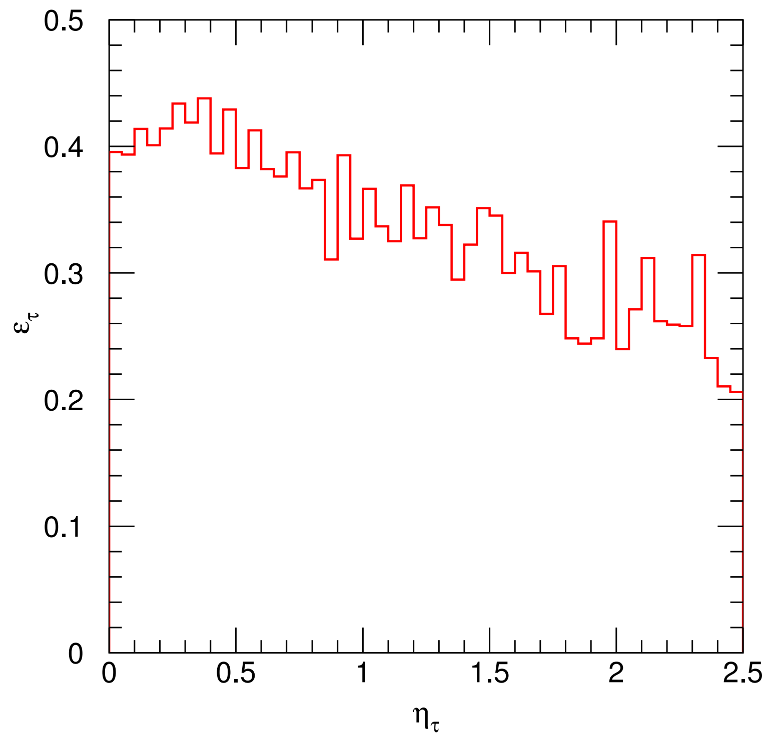
Gaussian fit gives 0.9992 ± 0.02615 for combined curve.

τ Reconstruction

τ's are important SUSY signature. Hadronic $\tau \Rightarrow 1$ track with $p_T > 2\,\mathrm{GeV}$, $E_{T,\mathrm{had}} \neq 0$, and narrow shower in EM calorimeter.

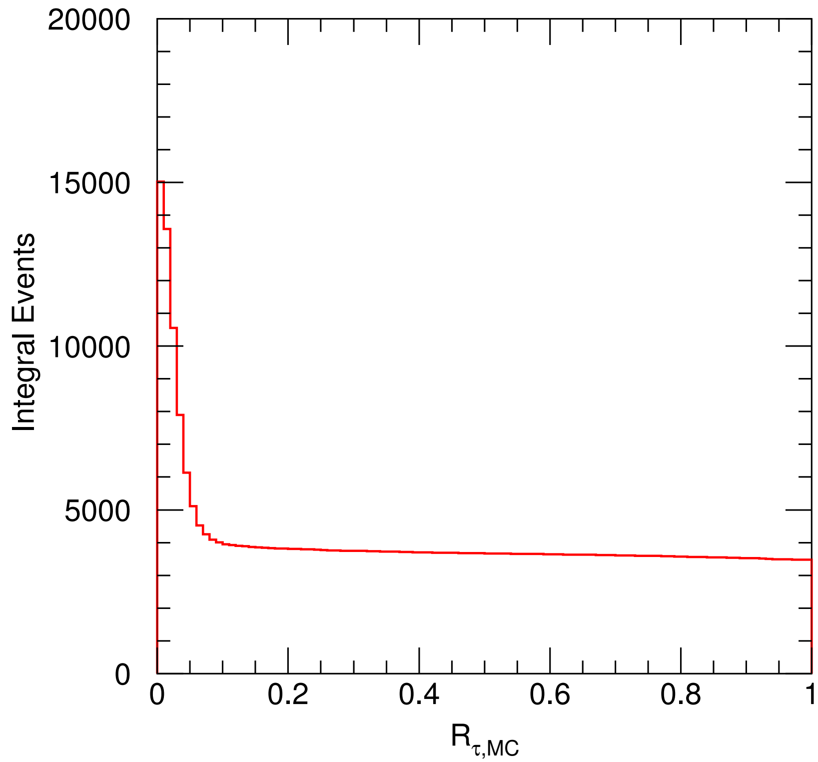
Shower shape L_τ distributions for τ's and jets before (dashed) and after (solid) track cuts and resulting efficiency for $E_{T,\mathrm{vis}} > 35\,\mathrm{GeV}$:

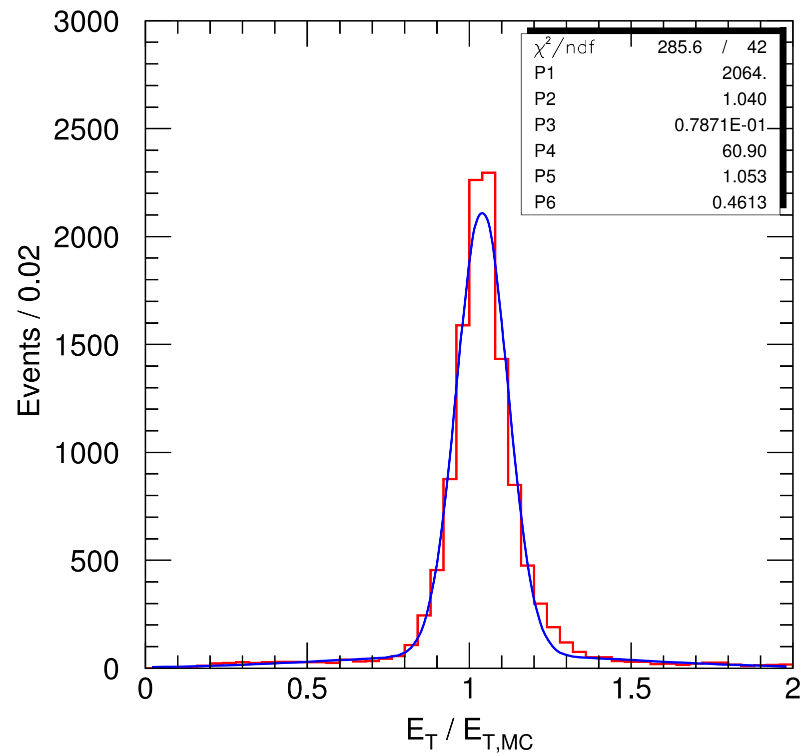




ATLAS

Matching in R of reconstructed to MC τ's and E_T resolution:

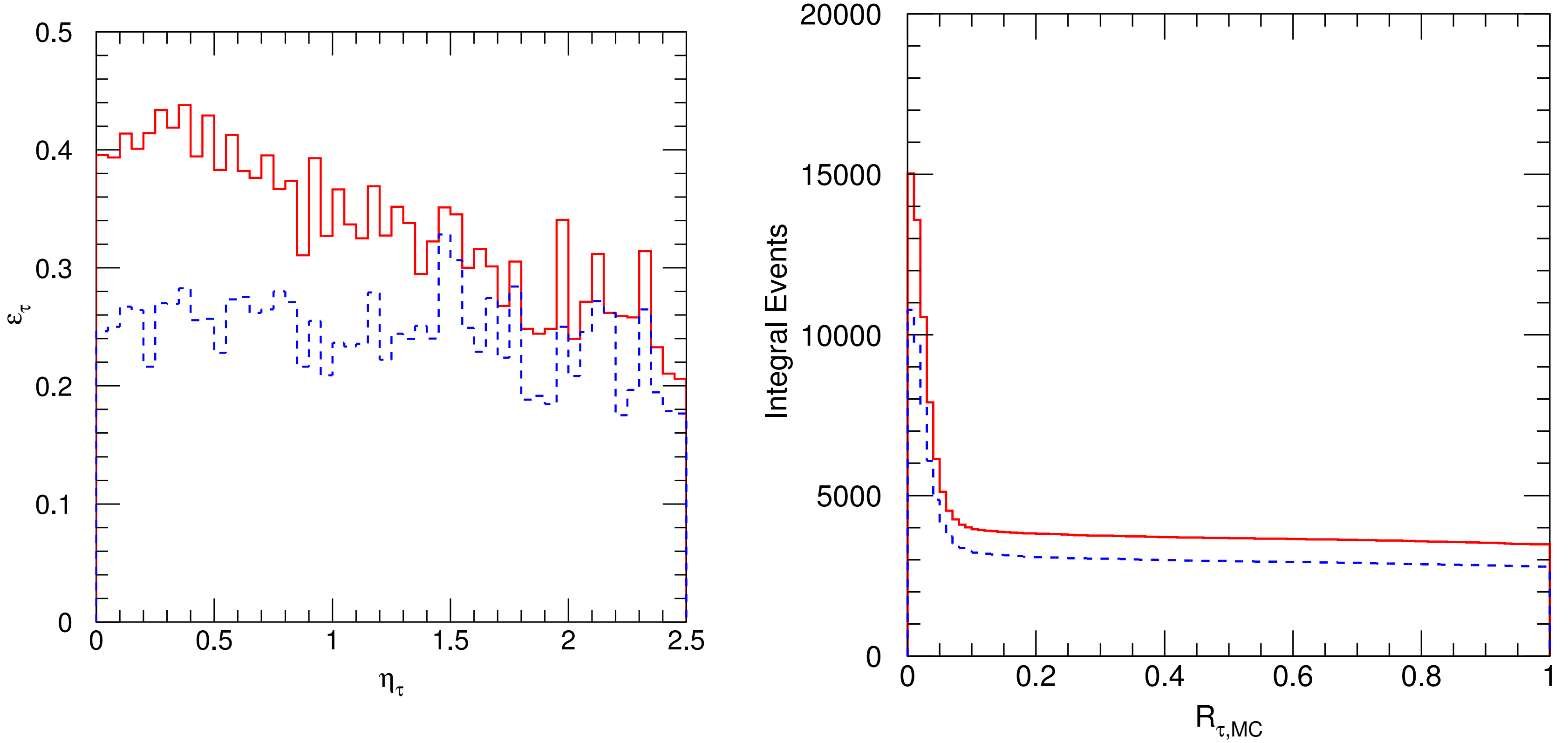




Significant background from mis-identified jets; $S/B \approx 2.8$.

Energy calibration for τ's with MC match is roughly OK.

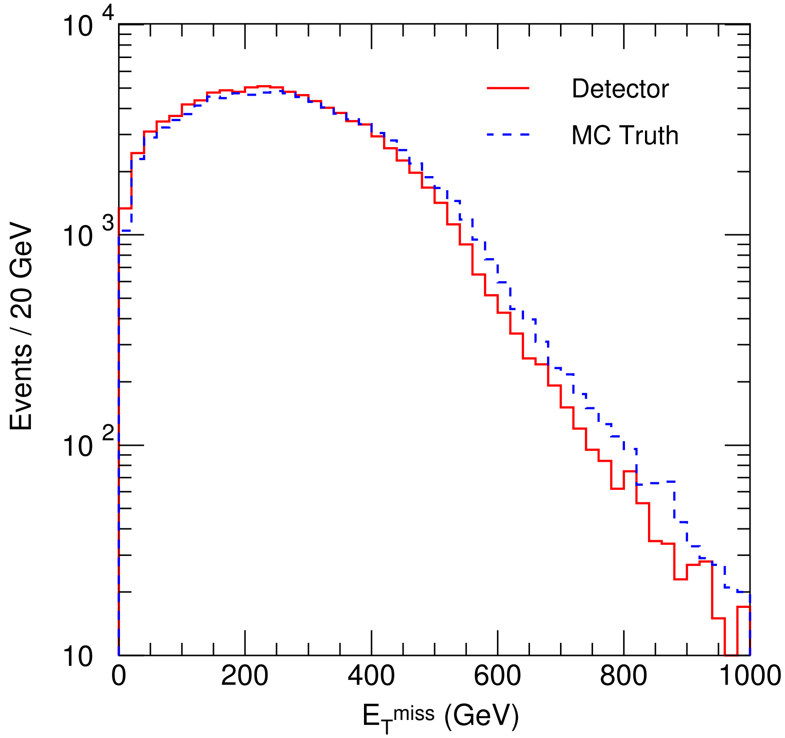
Just before Athens, included calorimeter noise with 2σ cut but no pileup. Efficiency is worse, especially at low η, and S/B also degraded:

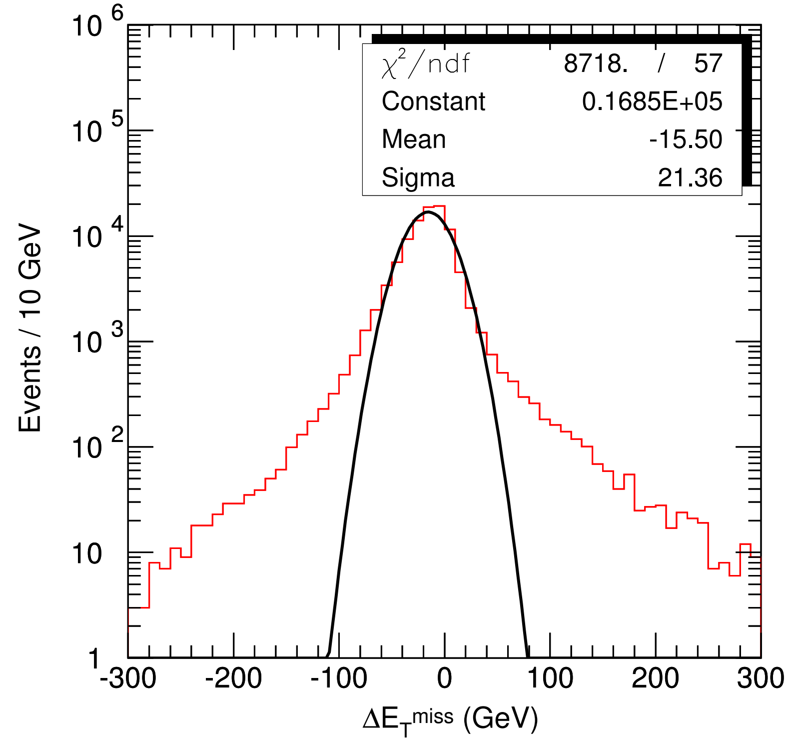


Need to retune τ selection cuts including noise and pileup.

$\not{E}_T$ Reconstruction

Observe $-15\,\mathrm{GeV}$ shift in mean compared to Monte Carlo, not seen in $A \rightarrow \tau\tau$ events:





Resolution approximately given by $0.76\sqrt{\sum E_T}$ but degrades at large $\sum E_T$. Slightly worse when noise is included.

ATLAS

SUSY Physics with Full Simulation

Use Point 5 selection cuts from *TDR*:

- ≥ 4 jets with $E_T > 100, 50, 50, 50\,\mathrm{GeV}$;
- $M_{\mathrm{eff}} > 800\,\mathrm{GeV}$;
- $\not\!\!E_T > \max(100\,\mathrm{GeV}, 0.2 M_{\mathrm{eff}})$.

Then expect negligible SM background, so just show SUSY distributions.

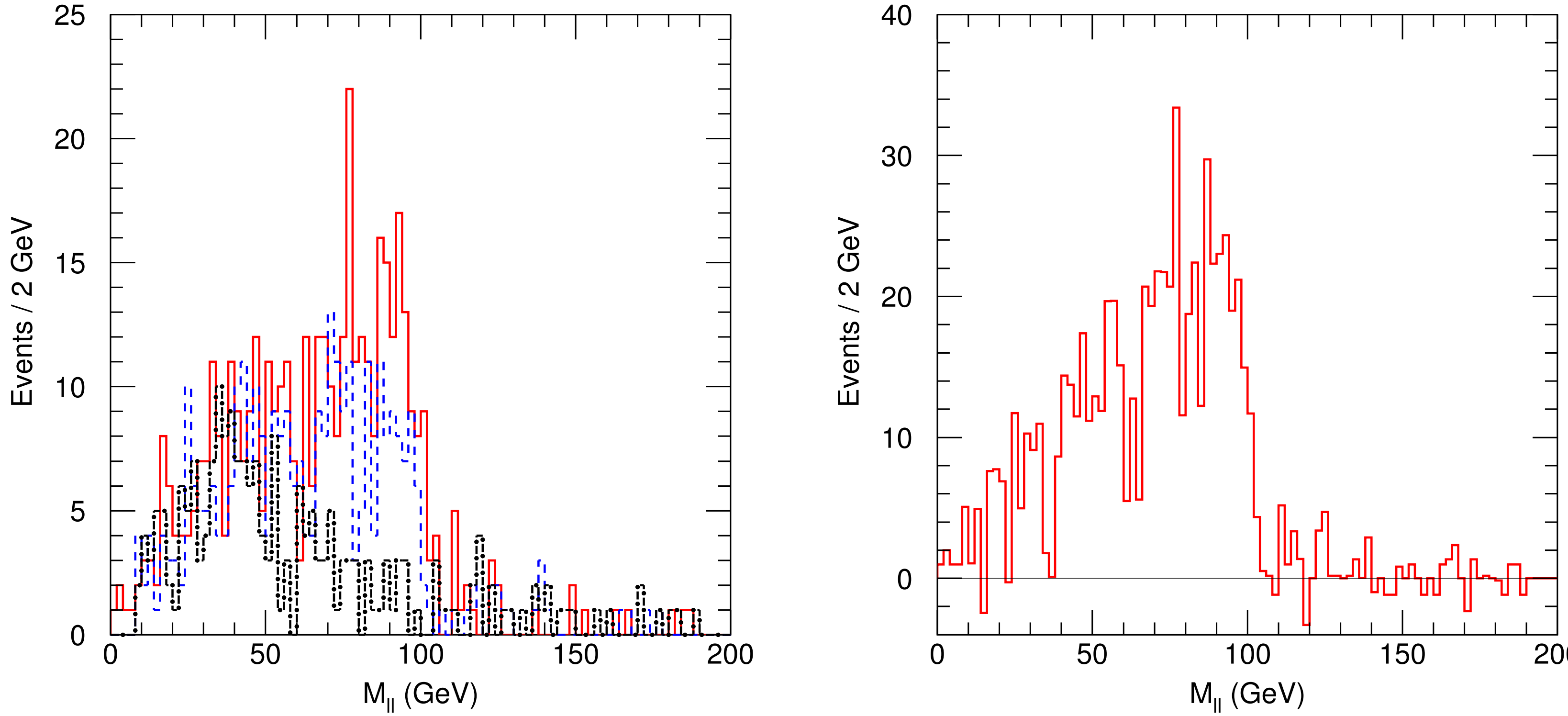
Recall $\tilde{\chi}_2^0 \to \tilde{\ell}_R^{\pm} \ell^{\mp} \to \tilde{\chi}_1^0 \ell^+ \ell^-$ has endpoint at

$$M_{\ell\ell}^{\max} = \sqrt{(M_{\tilde{\chi}_2^0}^2 - M_{\tilde{\ell}}^2)(M_{\tilde{\ell}}^2 - M_{\tilde{\chi}_1^0}^2)/M_{\tilde{\ell}}^2} = 100.16\,\mathrm{GeV}.$$

$e^+e^- + \mu^+\mu^- - e^{\pm}\mu^{\mp}$ cancels backgrounds from independent decays.

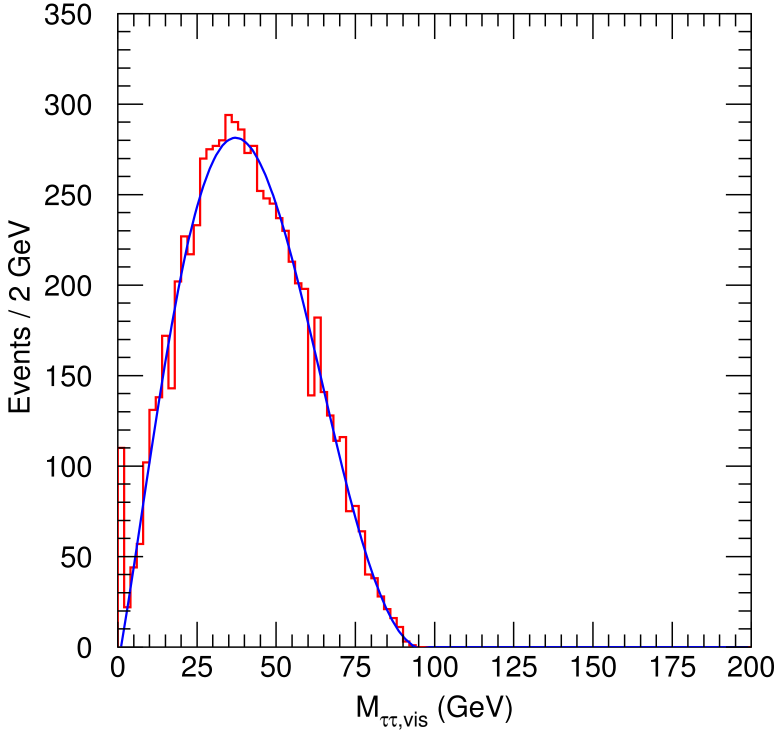
Correct E_e scale by 1.017 and weight each electron by 1.16 for relative acceptance. Then find correct endpoint after subtraction.

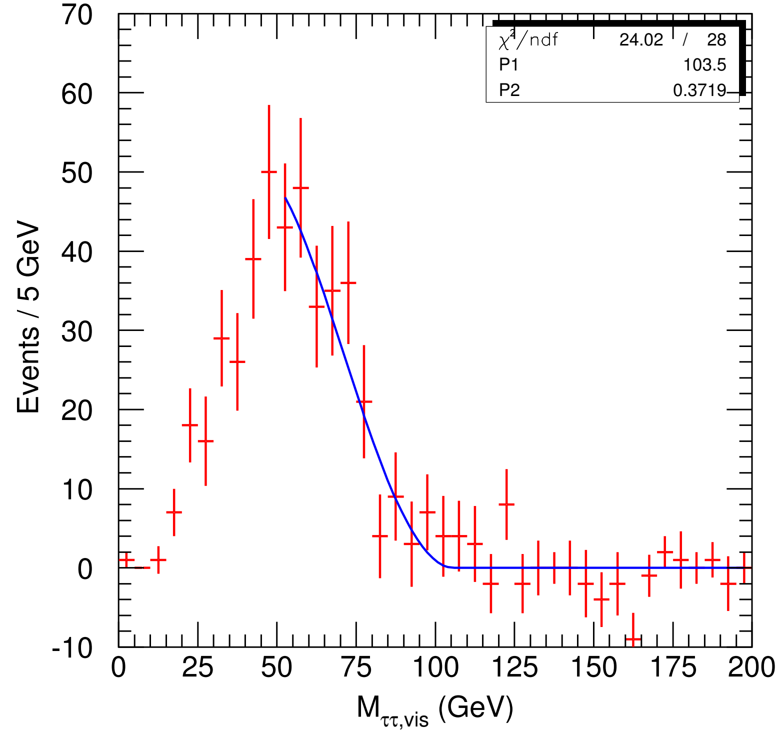
$\mu^+\mu^-$, e^+e^-, $e^\pm\mu^\mp$, and weighted $e^+e^- + \mu^+\mu^- - e^\pm\mu^\mp$ masses:



Main source of $\tilde{\chi}_2^0$ is $\tilde{q}_L \to \tilde{\chi}_2^0 q$. Assume 2 hardest jets are from $\tilde{q}_L$ and combine with dileptons. Find approximately right endpoints, but tails not yet understood.

For $\tau^+\tau^-$ use all Monte Carlo $\tilde{\chi}_2^0 \to \tilde{\tau}_1^\pm \tau^\mp$ events to find expected $M_{\tau\tau,\mathrm{vis}}$ distribution. Fit shape to reconstructed $\tau^+\tau^- - \tau^\pm\tau^\pm$ mass:

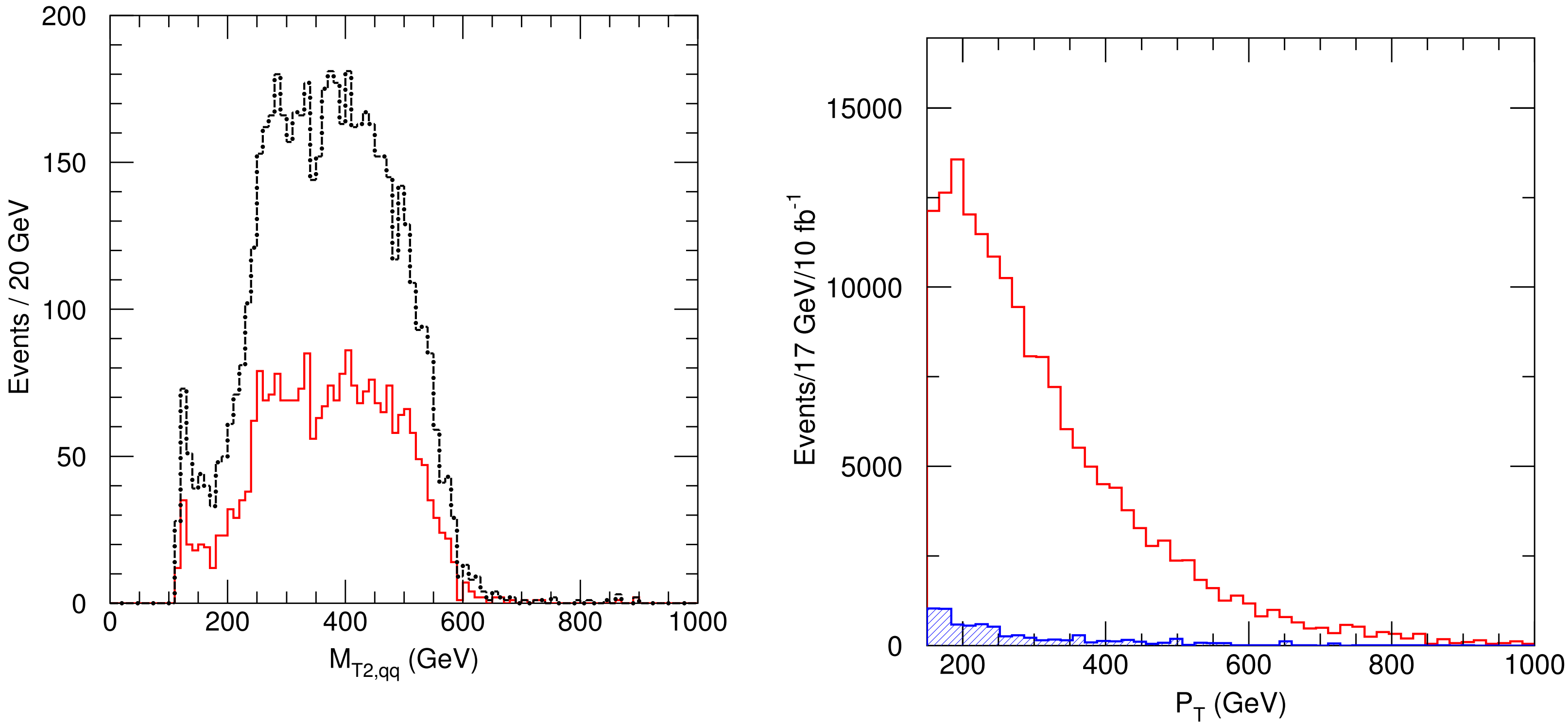




Fit gives $103.5 \pm 4.9\,\mathrm{GeV}$, consistent with $98.3\,\mathrm{GeV}$. Sensitive to fit range since $M_{\tau\tau,\mathrm{vis}}$ distorted by cuts at low mass. Shape also depends on τ polarizations, but effect not easy to observe [Vacavant].

ATLAS

$\tilde{q}_R\tilde{q}_R \to \tilde{\chi}_1^0 q \tilde{\chi}_1^0 q$ gives 2 jets + $\not\!\!E_T$. Veto jets with $E_T > 25(50)$ GeV and plot M_{T2} using known $M_{\tilde{\chi}_1^0}$. True endpoint is 611 GeV. Compare with single jet distribution for Point 6 [Note, TDR]:



Much better result from full simulation using M_{T2} than from fast simulation using p_T(!).

Athena Outlook

Athena reconstruction works — with real data we could start doing physics. But much remains to be done.

Concentrate here on combined reconstruction and physics issues:

Jets

- Improve H1 calibration, perhaps using E/V rather than E_T/cell. Include muons. Calibration for identified clusters?
- Study clustering contribution to resolution. Could use single particles and $R = 0.4$ single jets from MC events.
- Develop in situ calibration from physics data, e.g. $Z+\mathrm{jet(s)}$.
- Study preclustering. Is jet recalibration from ESD practical?
- Investigate jet corrections for measurements like $\ell\ell q$ endpoint.
- Study SUSY events below $\ell\ell q$ threshold (not seen with Atlfast).

Muons

- Understand source(s) of $\sim 4\%$ background in SUSY sample.
- Implement calorimeter and tracking isolation for muons.

Electrons

- Study energy calibration and apparent $e/\mathrm{jet} \sim 10^{-3}$.
- Fix `isem()` calorimeter cuts to allow subsequent selection changes. Include calorimeter and tracking isolation.
- Study E/p matching in endcap and TRT as pion veto.

Taus

- Improve efficiency and jet rejection including noise. Try tracking isolation, Heldmann's likelihood.
- Study τ polarization measurement and impact on visible $M_{\tau\tau}$.
- Fix double τ's from sliding window algorithm.

- Revisit τ energy calibration using experience from jets.
- Study soft τ's for SUSY coannihilation point.

Missing Energy

- Investigate offset and variation with $\sum E_T$ seen in SUSY sample.

Vertexing

- Develop primary vertex algorithm that works with pileup.
- Get b tagging in Athena! Then use it.

New Work

- Redo everything including pileup.
- Measure partial rates $\Leftrightarrow$ branching ratios. Luminosity?

Goal for DC2 physics (Athena 9.0.0) should be reconstruction closer to realizing design goals of ATLAS detector.

References

[Athens] Talks by D. Costanzo, F. Paige, and D. Tovey, Athens Physics Workshop, `http://agenda.cern.ch/fullAgenda.php?ida=a031081`.

[Note] M. Biglietti, et al., ATL-PHYS-2004-011.

[Vacavant] Talk by L. Vacavant, Lund Physics Workshop, `http://agenda.cern.ch/fullAgenda.php?ida=a0159`.

[TDR] ATLAS Collaboration, *Detector and Physics Performance Technical Design Report*, CERN/LHCC 99-14.